HSPF Hydrologic Model Calibration for Big Elk Creek, Oregon

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Introduction

Water quality monitoring in Big Elk Creek has shown episodic violations of Oregon's water quality standard for *E. coli* indicator bacteria, resulting in the need for a Total Maximum Daily Load (TMDL). As part of TMDL development, a calibrated watershed model is needed to investigate alternative pollutant load reduction scenarios. This document outlines the configuration of the Big Elk Creek Watershed model, hydrologic calibration methods, model results, and results of uncertainty analysis of model parameter values and predictions.

Site Description

The 57,000 acre Big Elk Creek Watershed (HUC 1710020402) is located in the Mid-Coast Basin of western Oregon (Figure 1). The watershed is characterized by mountainous terrain in the south and southeast headwater regions and gently sloping lands near the confluence of Big Elk Creek and the Yaquina River in the north. Soils belong to Soil Hydrologic Group B (moderately low runoff potential) and Group C (moderately high runoff potential) (U.S.D.A. Natural Resource Conservation Service, 2010). Forest cover predominates, with human development generally restricted to the broad valleys in the middle and lower portions of the watershed. Agricultural activities (livestock grazing and cropping) occur in these areas, and timber management is practiced on the watershed's forested slopes and ridgetops. Approximately 500 residents live in and around the communities of Harlan and Elk City, and land ownership is divided among private individuals, the timber industry, and public agencies (U.S.D.A. Forest Service, 1995). Federal lands are a part of the Siuslaw National Forest.

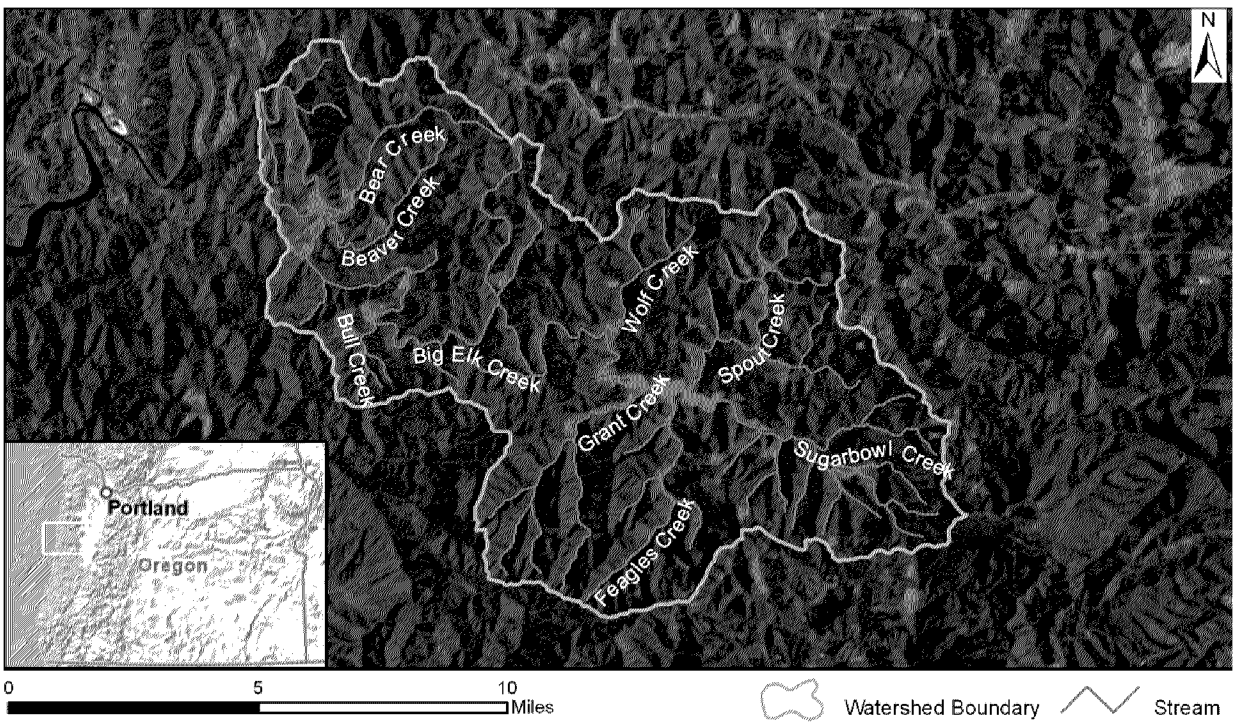


Figure 1. Aerial view of the Big Elk Creek Watershed.

The watershed's maritime climate is characterized by mild, wet winters and cool, dry summers. Average annual precipitation is 67 inches at the Summit weather station, located 5 miles northeast of the Big Elk Creek Watershed. PRISM average annual precipitation data (PRISM Climate Group, 2011) show wetter conditions in the upper portions of the watershed, which reach elevations of 3,000 feet and greater (Figure 2). Mild winter temperatures prevent significant accumulation of snow throughout the watershed. Air temperature data from the Corvallis Water Bureau weather station, located 5 miles east of the Big Elk Creek Watershed, show daily highs consistently above 40°F (Figure 3). Observations of snow depth at the nearby Summit and Alsea FH Fall Creek weather stations show that snow accumulation is uncommon in the region (Table 1).

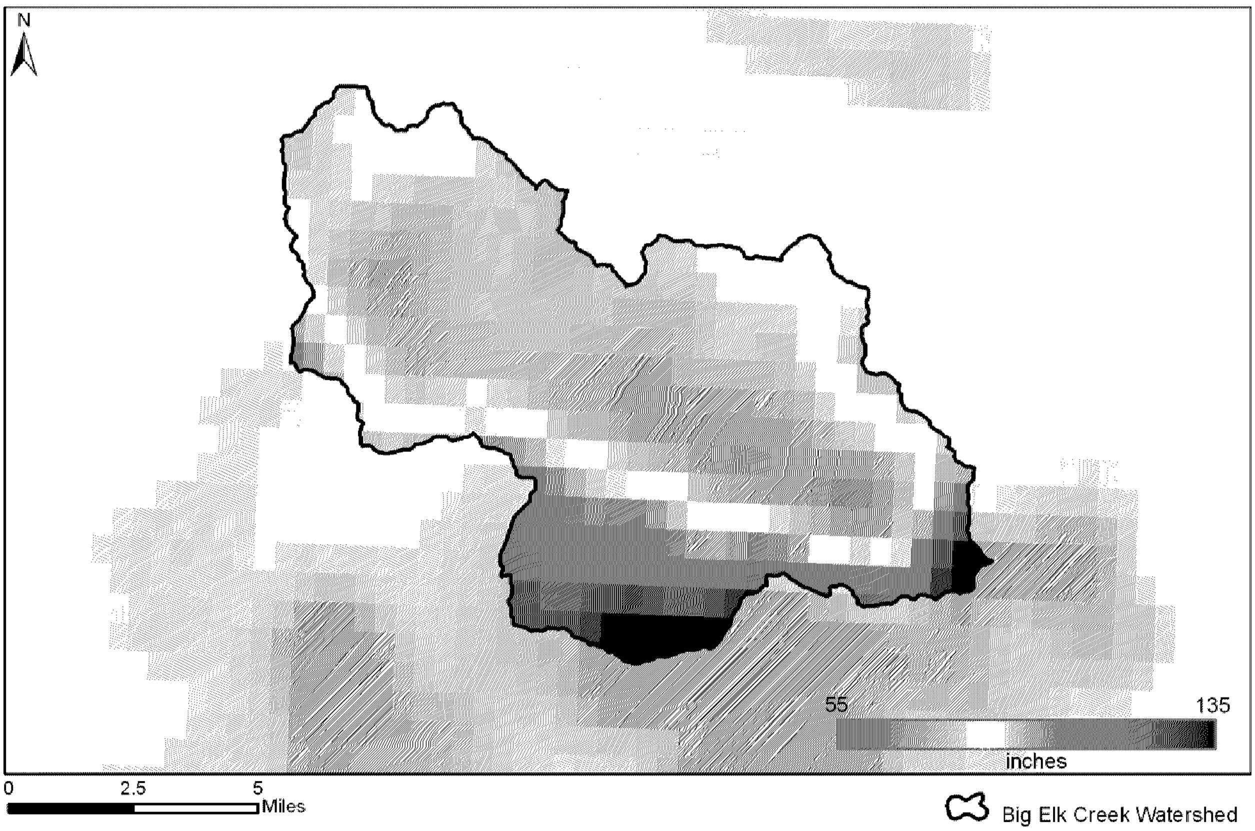


Figure 2. Mean annual precipitation (PRISM Climate Group, 2011).

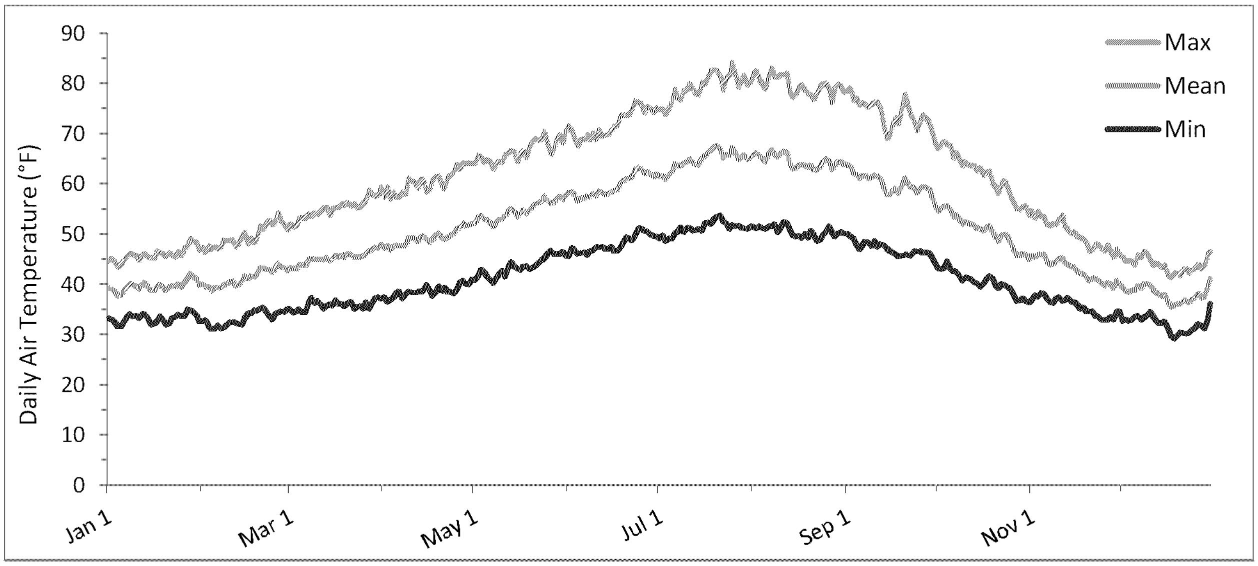


Figure 3. Maximum, mean, and minimum daily air temperature at the Corvallis Water Bureau weather station. Daily values are calculated as the mean of reported values from 1985-2006.

Table 1. Number of days with daily snow cover equal to zero inches by month over station period of record.

Month	Summit (358182)			Alsea FH Fall Creek (350145)		
	25th Percentile	Median	75th Percentile	25th Percentile	Median	75th Percentile
January	26	29	31	31	31	31
February	24.5	28	28	28	28	28
March	28	31	31	31	31	31
April	30	30	30	30	30	30
May	31	31	31	31	31	31
June	30	30	30	30	30	30
July	31	31	31	31	31	31
August	31	31	31	31	31	31
September	30	30	30	30	30	30
October	31	31	31	31	31	31
November	29	30	30	30	30	30
December	26	30	31	31	30	31

Source: NOAA Snow Climatology

Model Selection and Conceptual Design

Hydrologic modeling of the Big Elk Creek Watershed was completed using the Hydrologic Simulation Program – Fortran (HSPF). HSPF is an EPA-supported watershed model that is commonly used for TMDL development. It applies physically-based algorithms that capture surface and subsurface hydrologic processes to simulate watershed runoff and in-stream hydraulics. Runoff processes represented in HSPF include infiltration excess overland flow, interflow, and groundwater outflow. Important water balance components such as canopy interception, evapotranspiration, and deep groundwater loss are considered for runoff accounting. Algorithms are included to simulate runoff routing through a stream network based on user-defined channel dimensions and hydraulic relationships.

Model Configuration

Watershed Segmentation

A key step in the configuration of an HSPF model is watershed segmentation. Watershed segmentation refers to the division of the study watershed into multiple land segments and stream reach segments. A land segment is an area of uniform hydrologic response. Land segments, therefore, differ from one another in their meteorological inputs, land cover, soil properties, topography, etc. Multiple stream reach segments can be defined to account for natural drainage or land ownership boundaries, desired locations for model output (e.g., at flow or water quality monitoring stations), or variation in channel hydraulic properties.

Data used for segmentation of the Big Elk Creek Watershed included the NLCD 2001 land cover dataset, NRCS SSURGO soil data for Lincoln County and Benton County, OR, PRISM 1971 – 2000 average annual precipitation (PRISM Climate Group, 2011), NHDPlus drainage and hydrography data, and water quality monitoring locations reported in the ODEQ LASAR system.

HSPF land segments are defined in the PERLND (pervious land) and IMPLND (impervious land) modules. Pervious and impervious land segments represented in the Big Elk Creek Watershed HSPF model are summarized in Table 2.

Table 2. Land segments in Big Elk Creek Watershed HSPF model.

Land Segment	Land Cover	Surface Permeability	Precipitation Regime
PERLND 111	Forest	Low	Wet
PERLND 112	Forest	Low	Dry
PERLND 121	Forest	High	Wet
PERLND 122	Forest	High	Dry
PERLND 211	Pasture	Low	Wet
PERLND 212	Pasture	Low	Dry
PERLND 221	Pasture	High	Wet
PERLND 222	Pasture	High	Dry
PERLND 311	Developed	Low	Wet
PERLND 312	Developed	Low	Dry
PERLND 321	Developed	High	Wet
PERLND 322	Developed	High	Dry
IMPLND 301	Developed	Impervious	Wet
IMPLND 302	Developed	Impervious	Dry

Below is a review of the steps applied to define land segments:

1. NLCD land use classes were aggregated into three general classes: developed, forest, and pasture (Table 3; Figure 4). Note that urban development is negligible in the Big Elk Creek watershed. A review of aerial photos reveals that areas designated as *developed* in the NLCD are generally forest roads. Aerial photos also show that several areas designated as *barren* or *shrub* in the NLCD dataset were once forested and recently harvested. Similarly, most areas classified as *grassland* are pasture lands.

Table 3. Land cover lookup table. Value in parentheses are NLCD classification codes.

Aggregated Land Cover Class	NLCD Land Cover Class
Developed	Developed Open Space (21), Low Intensity (22) & Medium Intensity (23)
Forest	Forest Evergreen (42), Deciduous (41) & Mixed (43); Shrub (52); Barren (31); Wetland Woody (90) & Herbaceous (95)
Pasture	Pasture (81); Grassland (71)

2. Surface permeability throughout the Big Elk Creek Watershed was classified as *low* (surface Ksat = 1 in/hr) or *high* (surface Ksat = 50 in/hr), based on SSURGO soil data (Figure 4). Soils with missing infiltration data in the SSURGO database belong to the silty clay loam textural class and were assumed to have low surface permeability.

3. The Big Elk Creek Watershed was divided into *dry* (mean annual precipitation < 87 inches) and *wet* (mean annual precipitation > 87 inches) precipitation regime classes, based on PRISM average annual precipitation data (see Figure 2).

4. Developed land segments were divided into pervious and impervious segments by estimating the total and effective impervious area. Previous modeling studies have estimated that 90% of developed lands dominated by roads are impervious and that 95% of this impervious area is directly connected to a stream channel (Dinicola, 1990). Application of these estimates results in an estimated effective impervious area of 4% for the Big Elk Creek Watershed.

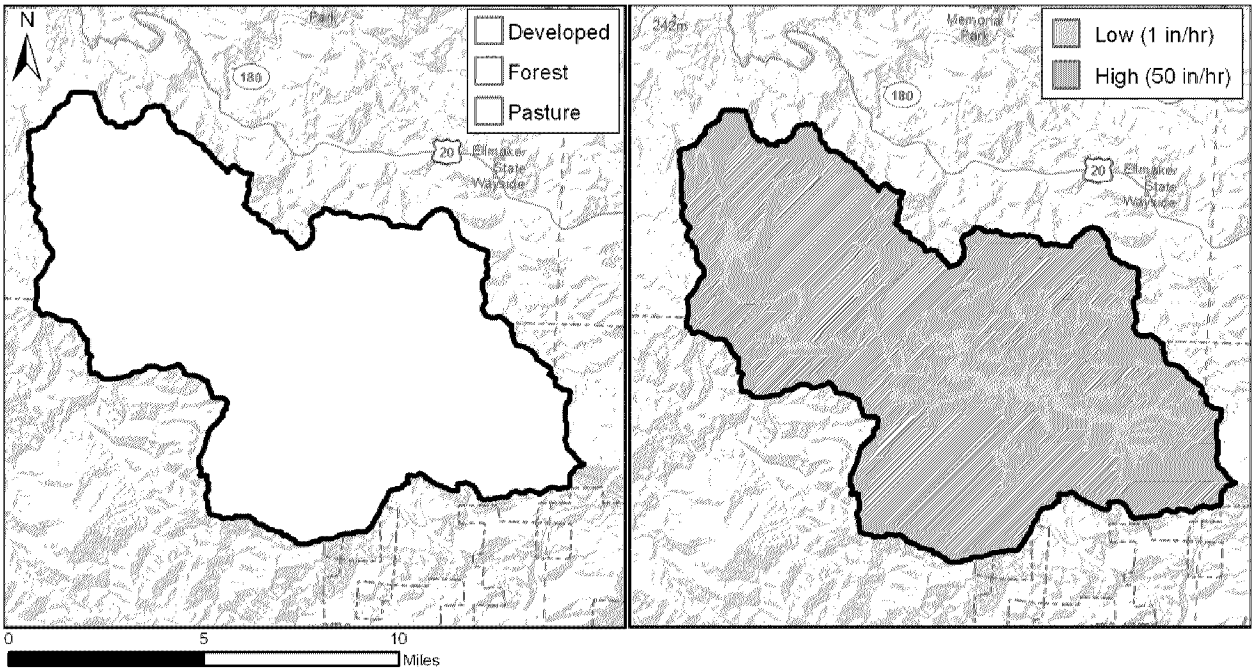


Figure 4. Big Elk Creek Watershed land cover (left) and surface saturated hydraulic conductivity (right).

As noted above, the process of watershed segmentation includes the definition of both land and stream reach segments. In HSPF, stream reaches are defined in the RCHRES module. Based on NHDPlus data and the location of water quality monitoring station locations (Figure 5), the Big Elk Creek Watershed stream network was divided into 18 stream reaches (Figure 6). The drainage area associated with each stream reach was delineated by merging upstream NHDPlus subwatershed polygons and by splitting polygons at monitoring station locations.

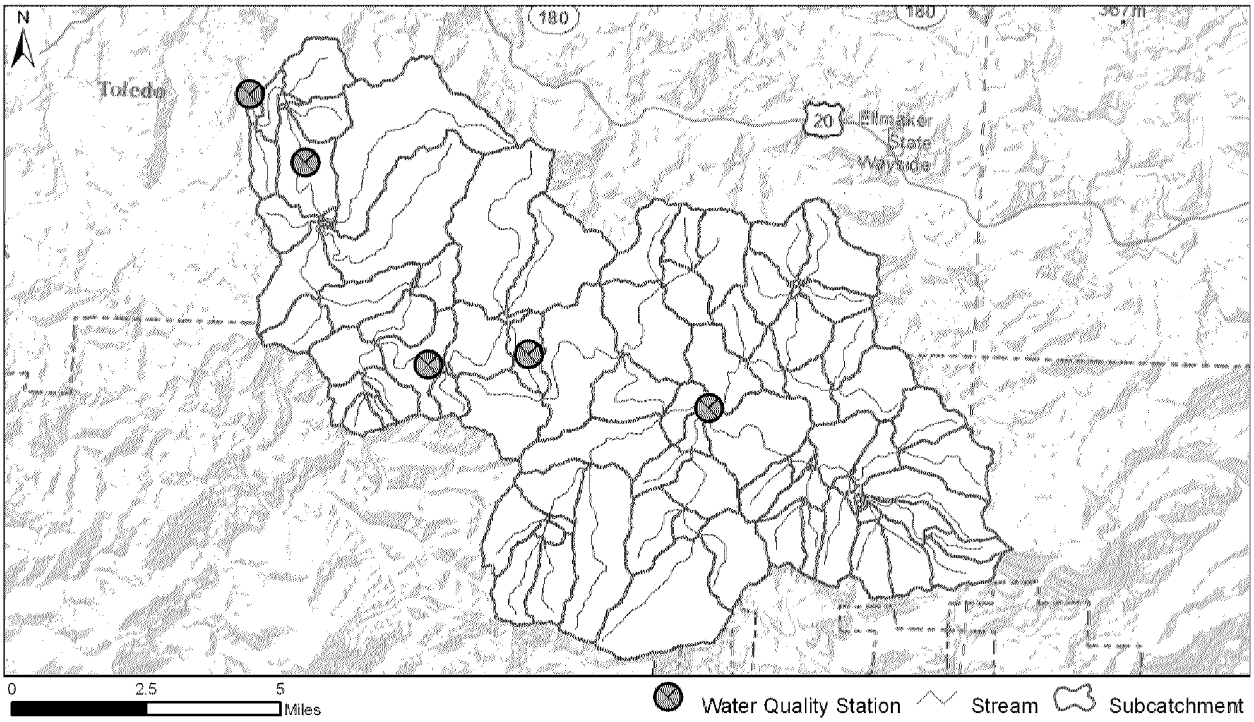


Figure 5. NHDPlus stream network and subwatersheds, and water quality monitoring locations.

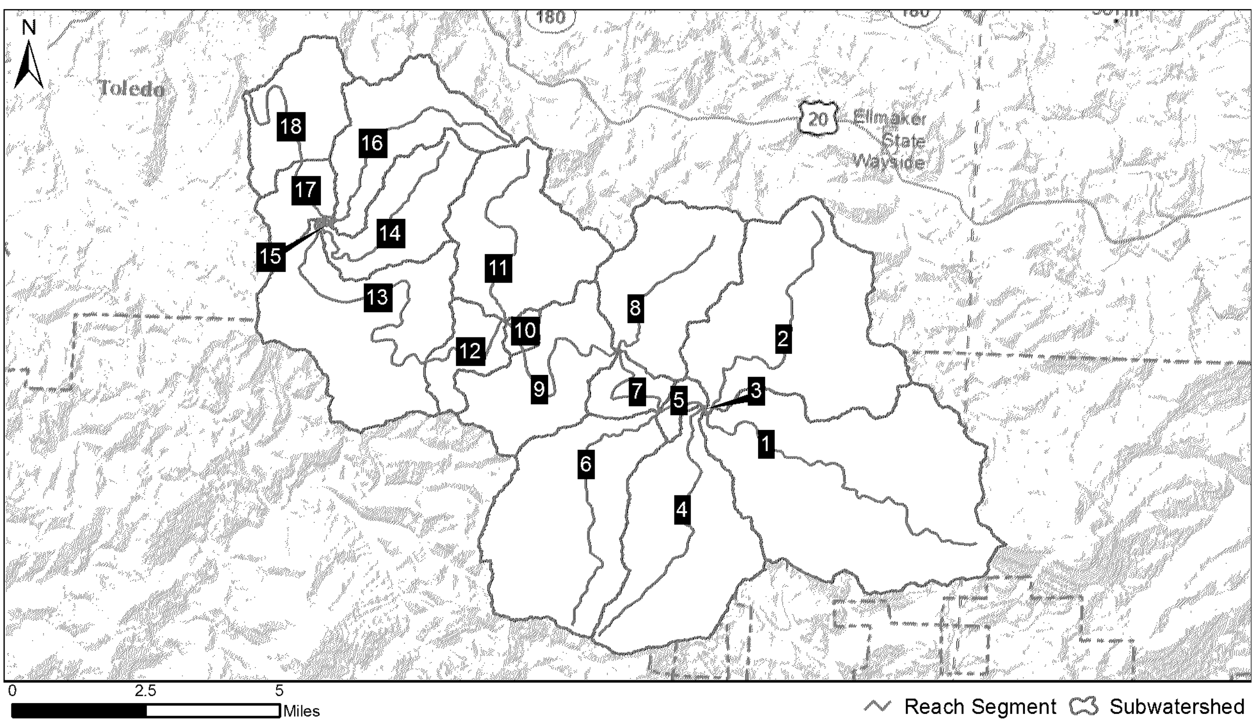


Figure 6. Big Elk Creek Watershed stream reach segmentation for HSPF modeling. Reaches are labeled with HSPF reach IDs.

Input Data

Required input for HSPF hydrologic simulation includes meteorological time series, definition of the stage-volume-discharge relationship for each reach segment, and initial estimates of model parameters.

Meteorological input data consisted of observed and estimated hourly precipitation and potential evapotranspiration (PET) over the period October 1, 1995 through December 31, 2010. Precipitation data from two National Climatic Data Center (NCDC) affiliated weather stations were included as model input. Data from the Alsea FH Fall Creek (ID# 350145) weather station were assigned to *wet* land segments, and data from the Summit weather station (ID# 358182) were assigned to *dry* land segments. Estimated PET at the Corvallis Water Bureau weather station (ID# 351877) was applied to all land segments. Characteristics of NCDC datasets used for developing HSPF meteorological input are summarized in

Table 4 and a map of weather station locations is provided in Figure 7. Below is a review of the steps applied to process raw NCDC data files:

1. Missing hourly/daily precipitation data from the Summit and Alsea FH Fall Creek weather stations were estimated from reported values at nearby stations, adjusted by the ratio of average monthly precipitation between stations for the corresponding month.

2. Missing minimum/maximum daily air temperature data from the Corvallis Water Bureau dataset were estimated from temperature observations at the Newport weather station, adjusted by the ratio of minimum/maximum monthly air temperature between stations for the corresponding month.

3. Daily precipitation data from the Alsea FH Fall Creek weather station were disaggregated to hourly values using WDMUtil software. WDMUtil algorithms disaggregate daily precipitation based on the hourly distribution of precipitation at nearby weather stations or a triangular distribution centered at the middle of the day if daily totals at nearby stations are not within 50%.

4. Daily PET data from the Corvallis Water Bureau station were computed using WDMUtil software. WDMUtil algorithms calculate daily PET from daily minimum/maximum air temperature and the Hamon equation.

5. Daily PET data from the Corvallis Water Bureau were disaggregated to hourly values using WDMUtil software. WDMUtil algorithms disaggregate daily PET based on site latitude and time of the year.

Table 4. NCDC data sets used to generate HSPF meteorological input. All data span the period 10/1/1995 through 12/31/2010.

Station Name	NCDC ID	Parameter	Frequency	% Missing
Alsea FH (Fall Creek)	350145	Precipitation	Daily	<1%
Corvallis Water Bureau	351877	Precipitation	Daily	1%
Corvallis Water Bureau	351877	Air Temperature	Daily	1%
Newport	356032	Precipitation	Daily	9%
Newport	356032	Air Temperature	Daily	16%
Summit	358182	Precipitation	Hourly	11%
Yaquina Bay	359581	Precipitation	Hourly	9%

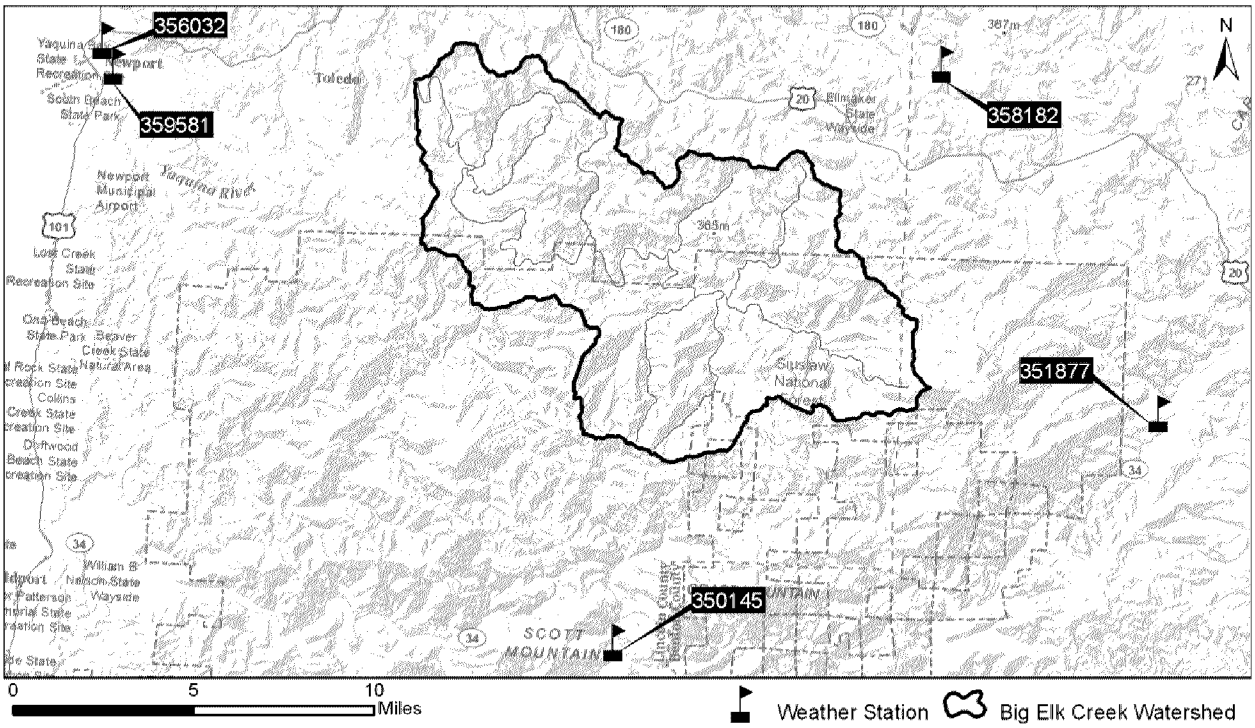


Figure 7. NCDC weather stations used for HSPF meteorological input.

The geometric and hydraulic properties of a given stream reach are defined in HSPF using a hydraulic FTABLE. The FTABLE contains information on the magnitude of stream discharge under various stage/volume conditions. FTABLES for Big Elk Creek and tributary reaches were developed according to methods outlined in BASINS Technical Note 2 (U.S. Environmental Protection Agency, 2007). Reaches were assumed to have compound trapezoidal geometry, with a single channel section and two floodplain sections. Bankfull channel geometry was estimated using NRCS regional hydraulic geometry regression equations developed for southwestern Oregon that relate upstream drainage area to bankfull mean depth and top width (Kuck, 2000). These dimensions served as the basis for remaining channel and floodplain geometry estimates. Stream discharges were estimated for several stages using the Manning equation.

The selection of initial HSPF parameter values followed guidelines presented in BASINS Technical Note 6 (U.S. Environmental Protection Agency, 2000). Some parameters values were estimated using site-specific datasets, others were assigned default/recommended values.

Model Calibration

Calibration of the Big Elk Creek Watershed HSPF model was completed using PEST software (Watermark Numerical Computing, 2002). PEST is an automated system for optimizing model parameter values. The program allows users to specify one or more groups of streamflow observations (e.g., daily mean flows or accumulated volumes over time) to serve as a benchmark for model calibration and attempts to minimize the error between observations and model output by performing several model runs with varied parameter sets.

Calibration Data

Direct measurements of streamflow in Big Elk Creek (and its tributaries) were not available for model calibration. Rather, two methods were applied to estimate Big Elk Creek flow characteristics (at the watershed outlet): 1) a modified application of the Drainage-Area Ratio method was used to estimate daily mean streamflow; and 2) USGS StreamStats flow duration regression equations were used to generate annual and monthly flow duration prediction intervals.

The Drainage-Area Ratio method is commonly applied to estimate streamflow in ungaged watersheds (Risley, Stonewall, & Haluska, 2008). The method assumes that area-normalized streamflow in the ungaged watershed is equal to that observed in a gaged reference watershed. Ungaged streamflow is therefore calculated as:

$$Q_u = Q_r \frac{A_u}{A_r}$$

where Q_u is daily mean streamflow in the ungaged watershed, Q_r is daily mean streamflow in the reference watershed, A_u is the drainage area of the ungaged watershed, and A_r is the drainage area of the reference watershed.

The Yaquina River Watershed served as the reference watershed for Big Elk Creek flow estimates. Daily flows have been monitored at the Yaquina River near Chitwood gaging station (ID# 14306030) by the Oregon Department of Water Resources since 1972. The watershed lies immediately north of the Big Elk Creek Watershed and the two are similar in size and land cover (Figure 8; Table 5). To account for precipitation differences between the Big Elk Creek Watershed (mean annual precipitation = 84 in.) and Yaquina River Watershed (mean annual precipitation = 74 in.), the standard Drainage-Area Ratio equation was modified to:

$$Q_u = Q_r \frac{A_u}{A_r} \frac{P_u}{P_r}$$

where P_u is average annual precipitation in the ungaged watershed and P_r is average annual precipitation in the reference watershed. Values of A_u, A_r, P_u, and P_r specific to the Big Elk Creek and Yaquina River watersheds can be found in Table 5.

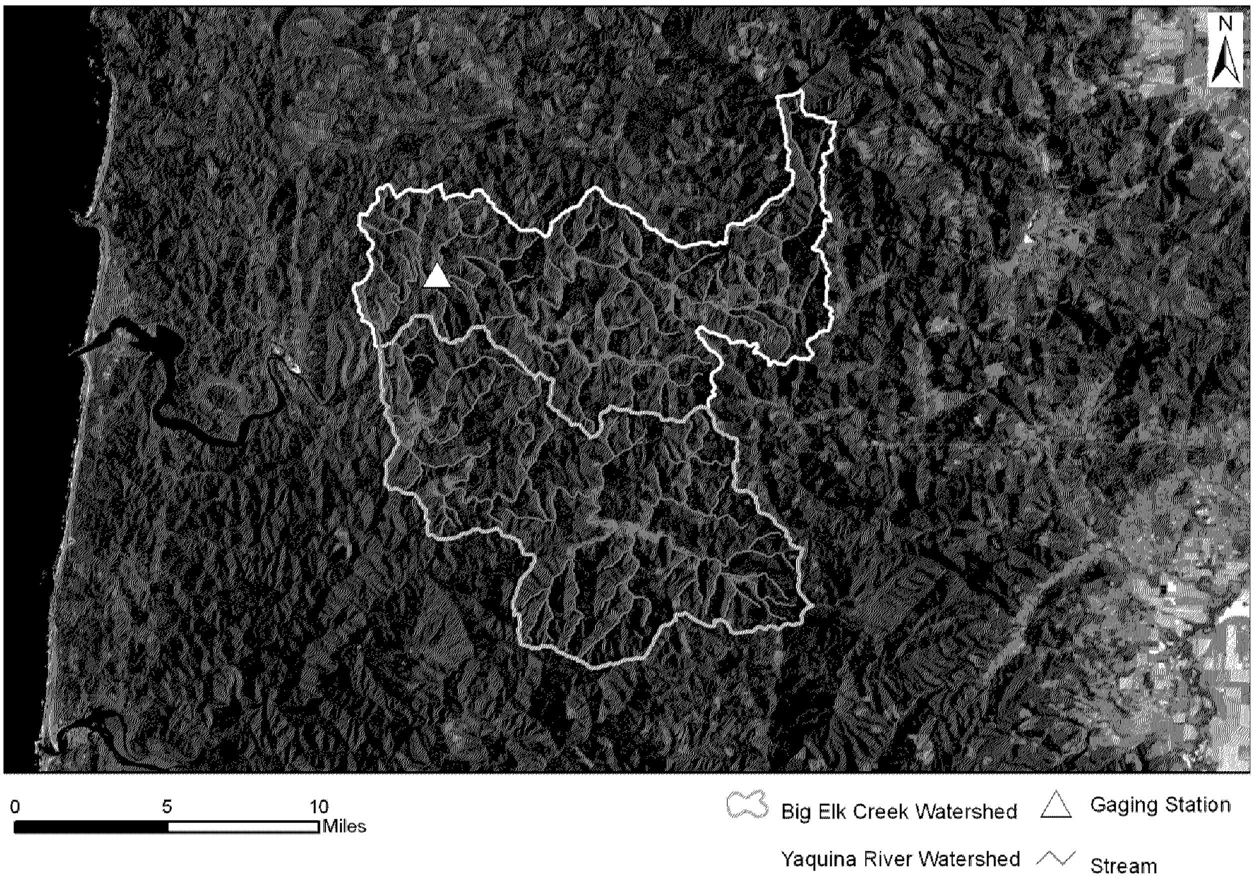


Figure 8. Location of the Yaquina River watershed and the Yaquina River near Chitwood gaging station (ODWR ID# 14306030).

Table 5. Big Elk Creek and Yaquina River watershed characteristics.

	Big Elk Creek	Yaquina River
Drainage Area (mi^2)	88.8 mi^2	70.8 mi^2
Mean Annual Precipitation (in.)	84 in.	74 in.
Mean Annual Temperature (°F)	52 °F	52 °F
Developed, Open	5%	7%
Barren	1%	1%
Forest, Deciduous	4%	6%
Forest, Evergreen	45%	35%
Forest, Mixed	28%	29%
Shrub/Scrub	11%	14%
Grassland	4%	6%
Pasture	1%	1%
Wetland, Woody	1%	1%

Drainage-Area Ratio estimates are assumed to reasonably reflect real-world Big Elk Creek flows. They are, however, subject to a level of error and uncertainty that is unquantified. For this reason, USGS StreamStats flow duration regression equations were used to generate an alternative dataset for evaluating model output. The USGS StreamStats program has developed regression equations to estimate streamflow statistics for gaged and ungaged watersheds throughout the US. For the state of Oregon, regional regression equations have been derived to predict daily mean streamflow magnitudes corresponding to 5, 10, 25, 50, and 95% exceedance probabilities on annual and monthly flow duration curves (i.e., Q5, Q10, Q25, Q50, and Q95 flows) (Risley, Stonewall, & Haluska, 2008). Several watershed characteristics are included as predictor variables for the Mid-Coast Region regressions (e.g., drainage area, mean annual precipitation, soil storage capacity). Values of predictor variables specific to the Big Elk Creek Watershed were obtained from the Oregon StreamStats online tool. Error statistics (standard error of the estimate) included with regression equations allowed for the calculation of prediction intervals for each flow duration statistic. Prediction intervals for Big Elk Creek annual flow duration statistics are illustrated in Figure 9.

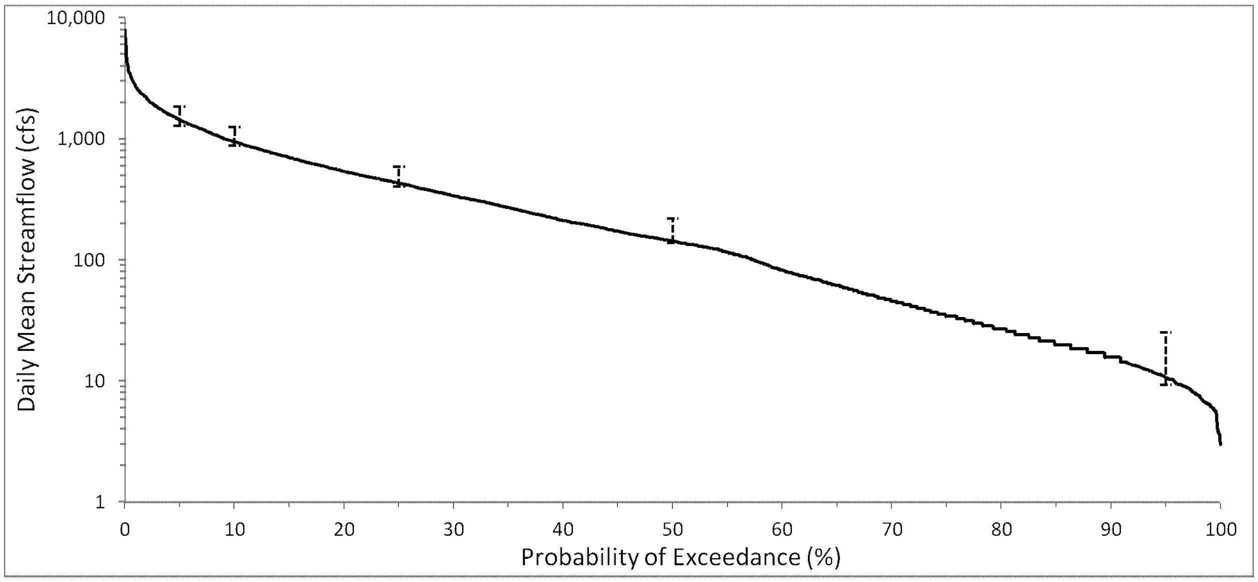


Figure 9. StreamStats flow duration prediction intervals for Big Elk Creek. The solid line is the Big Elk Creek flow duration curve generated using the Drainage-Area Ratio method.

<u>Calibration Criteria</u>

Criteria used to assess the level of agreement between estimated and predicted Big Elk Creek streamflow included:

- ±15% error in total flow volume (relative to the Drainage-Area Ratio estimate);
- ±15% error in summer (June-August) flow volume (relative to the Drainage-Area Ratio estimate);
- ±15% error in winter (December through February) flow volume (relative to the Drainage-Area Ratio estimate);
- ±20% error in flow volume for 18 storm periods (relative to the Drainage-Area Ratio estimate). Storms were identified from a review of precipitation and flow data;
- ±20% error in mean of storm peak flows (relative to the Drainage-Area Ratio estimate); and
- Annual and monthly flow duration statistics within prediction intervals calculated from StreamStats regression equations.

The above criteria incorporate aspects of the annual and seasonal water balance, storm response, and the frequency distribution of flows. Several of these statistics are used for manual calibration of HSPF models with HSPEXP calibration software (Lumb, McCammon, & Kittle, 1994). The 18 storms used for storm volume and peak flow calculations included at least one storm from each year in the calibration record and were representative of large and moderate to small sized rainfall-runoff events (Table 6). Stormflow duration was generally 7 to 10 days.

Table 6. Summary of storm periods used for model calibration.

Storm No.	Start	End	Flow Volume (acre-feet)	Peak Flow (cfs)
1	2/5/1996	2/17/1996	66,067	7,910
2	1/28/1997	2/7/1997	32,084	4,190
3	10/29/1997	11/6/1997	9,268	1,330
4	12/29/1998	1/4/1999	23,920	4,960
5	5/9/2000	5/19/2000	9,218	976
6	12/22/2000	12/29/2000	9,577	1,150
7	1/6/2002	1/16/2002	23,465	2,650
8	1/29/2003	2/7/2003	30,751	3,620
9	12/13/2003	12/18/2003	17,641	3,250
10	4/19/2004	4/29/2004	6,304	516
11	6/5/2005	6/15/2005	6,610	590
12	11/11/2005	11/19/2005	6,817	807
13	12/14/2006	12/17/2006	11,823	2,380
14	12/1/2007	12/11/2007	18,763	2,380
15	11/11/2008	11/19/2008	13,284	2,280
16	3/14/2009	3/21/2009	10,476	956
17	3/11/2010	3/19/2010	10,430	996
18	11/30/2010	12/5/2010	10,418	1,360

PEST Calibration

Model calibration using PEST begins by designating model parameters to be adjusted during the calibration process. For the Big Elk Creek Watershed HSPF model, the selection of parameters for adjustment (Table 7) was based on parameter estimation recommendations outlined in BASINS Technical Note 6 (U.S. Environmental Protection Agency, 2000). Note that seasonal variation in the interception (CEPSC) and lower zone evapotranspiration (LZETP) parameters was considered by requiring that values during the growing season (May-September) were 20% (forest cover) and 50% (pasture and developed cover) higher than non-growing season values.

Table 7. Parameters adjusted through PEST calibration.

Parameter Name	Parameter Description
LZSN000	Lower zone nominal soil moisture storage.
INFILT110	Index to mean soil infiltration rate (forest cover/low soil permeability segments).
INFILT120	Index to mean soil infiltration rate (forest cover/high soil permeability segments).
INFILT210	Index to mean soil infiltration rate (pasture cover/low soil permeability segments).
INFILT220	Index to mean soil infiltration rate (pasture cover/high soil permeability segments).
INFILT310	Index to mean soil infiltration rate (developed cover/low soil permeability segments).
INFILT320	Index to mean soil infiltration rate (developed cover/high soil permeability segments).
AGWRC000	Groundwater recession rate.
DEEPFR000	Fraction of infiltrating water lost to deep aquifers.
BASETP000	ET by riparian vegetation as active groundwater enters streambed.
AGWETP000	Fraction of watershed subject to direct evaporation from groundwater storage.
UZSN100	Nominal upper zone soil moisture storage (forest cover segments).
UZSN200	Nominal upper zone soil moisture storage (pasture cover segments).
UZSN300	Nominal upper zone soil moisture storage (developed cover segments).
INTFW100	Interflow coefficient (forest cover segments).
INTFW200	Interflow coefficient (pasture cover segments).
INTFW300	Interflow coefficient (developed cover segments).
IRC000	Interflow recession coefficient.
CEPSC100	Maximum precipitation interception (forest cover segments).
CEPSC200	Maximum precipitation interception (pasture cover segments).
CEPSC300	Maximum precipitation interception (developed cover segments).
LZETP100	Index to lower zone evapotranspiration (forest cover segments).
LZETP200	Index to lower zone evapotranspiration (pasture cover segments).
LZETP300	Index to lower zone evapotranspiration (developed cover segments).

PEST algorithms are designed to search for the set of parameter values that minimize the error between observed and modeled values. This error, termed the objective function, is calculated as the sum of squared prediction errors. The overall objective function can be comprised of multiple sub-objective functions, each representing the predictive error for unique observation groups. Here, a multi-objective function was constructed from 8 observation groups:

1. Log-transformed daily mean flows;
2. Annual flow volumes;
3. Summer (June - August) flow volumes;
4. Winter (December - March) flow volumes;
5. Storm volumes for 18 storm periods;
6. Storm peak flows for 18 storm periods;
7. Flow duration statistics (exceedance times of estimated Q5, Q10, Q25, Q50, and Q95 flows);
8. Baseflow index (the ratio of groundwater outflow to total outflow from pervious land segments).

Note that *observed* values of the above flow statistics were based on the daily flow time series generated for Big Elk Creek using the Drainage-Area Ratio method rather than actual streamflow measurements. The exception was the observed baseflow index, which was specified as 0.44.

PEST allows users to assign weights to individual prediction errors or a weighting function to a group of prediction errors for objective function calculations. This prevents a single observation or observation group from having an inflated influence on the calibration process. Here, weights and weighting functions were assigned so that the contributions of each observation group to the initial objective function value were equal.

Calibration Results

Model outputs presented in this section focus on data pertaining to the calibration objective function and calibration criteria listed above.

Observed and modeled Big Elk Creek flow volumes and storm peak flows are summarized in Table 8. Flow statistics meet model performance criteria outlined above.

Table 8. Observed and calibrated Big Elk Creek flow statistics.

Flow Statistic	Observed	Modeled	Percent Error
Total Volume (acre-ft)	3,836,430	3,818,404	-0.5%
Summer Volume (acre-ft)	152,460	151,315	-0.8%
Winter Volume (acre-ft)	2,044,705	1,960,670	-4.1%
Storm Volume (acre-ft)	316,917	280,874	-11.4%
Mean Storm Peak (cfs)	2,350	2,176	-7.4%
Baseflow Index	0.44	0.41	-6.0%

Modeled and observed Big Elk Creek annual flow duration curves are illustrated in Figure 10. Modeled flow duration statistics fall within the prediction intervals generated using USGS StreamStats regressions.

Modeled Big Elk Creek monthly flow duration curves are provided in Figure 11 and Figure 12. The agreement between modeled flow duration statistics and USGS StreamStats prediction intervals is generally good, with modeled statistics within prediction intervals for the majority of months. Exceptions tend to occur where the dataset used for PEST calibration is outside of StreamStats prediction intervals.

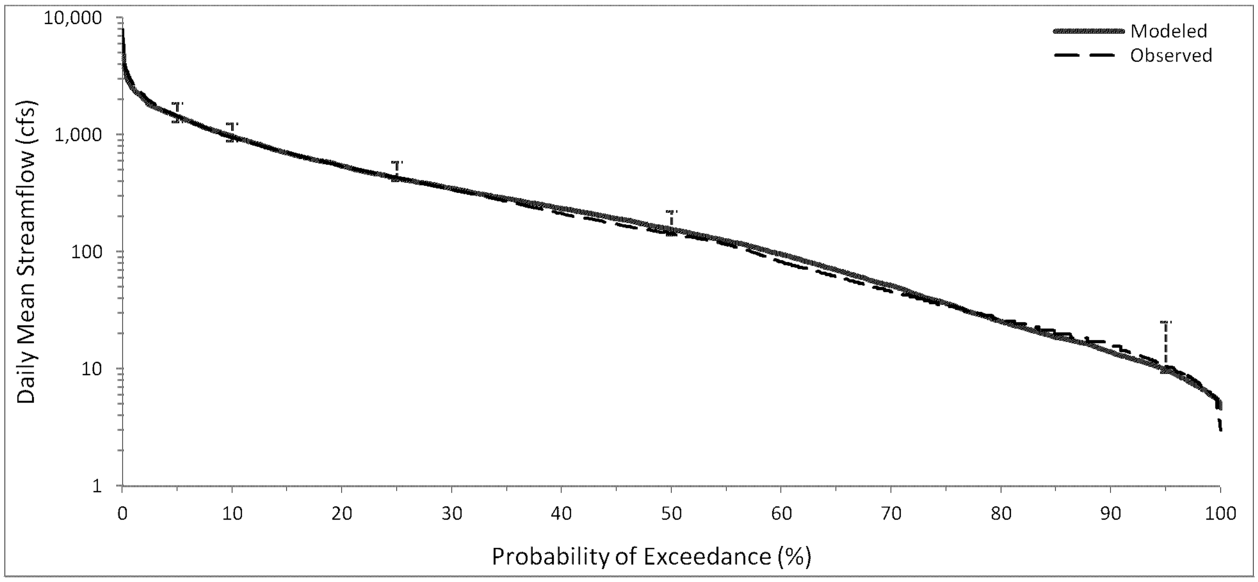


Figure 10. Big Elk Creek annual flow duration curve. Error bars are prediction intervals calculated from USGS StreamStats regional regression equations.

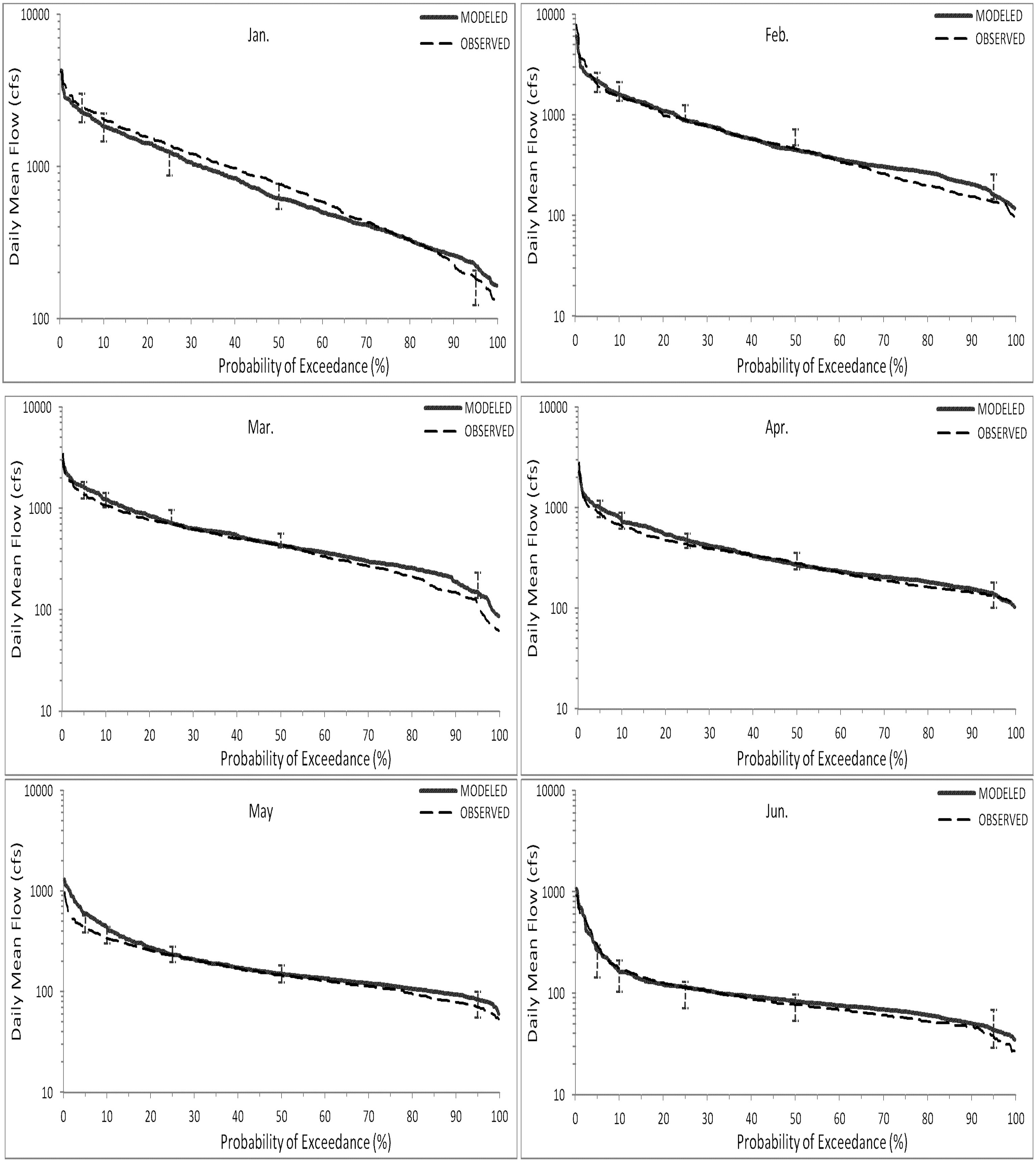
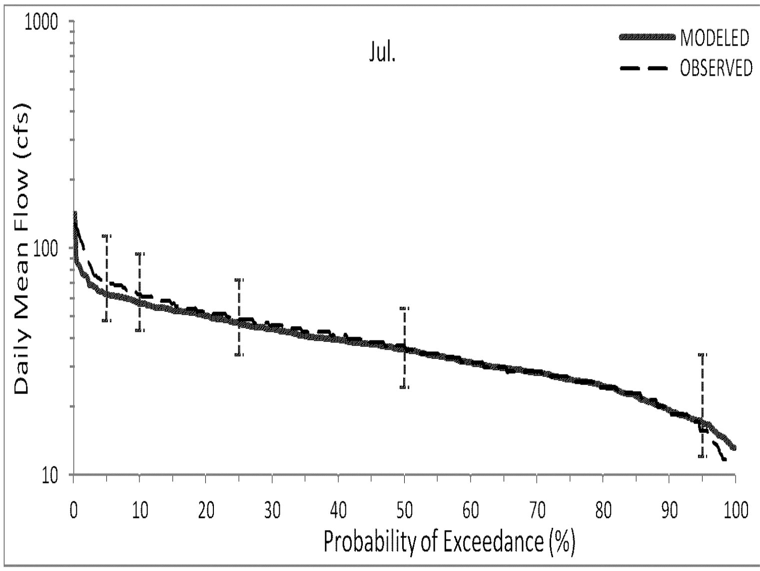
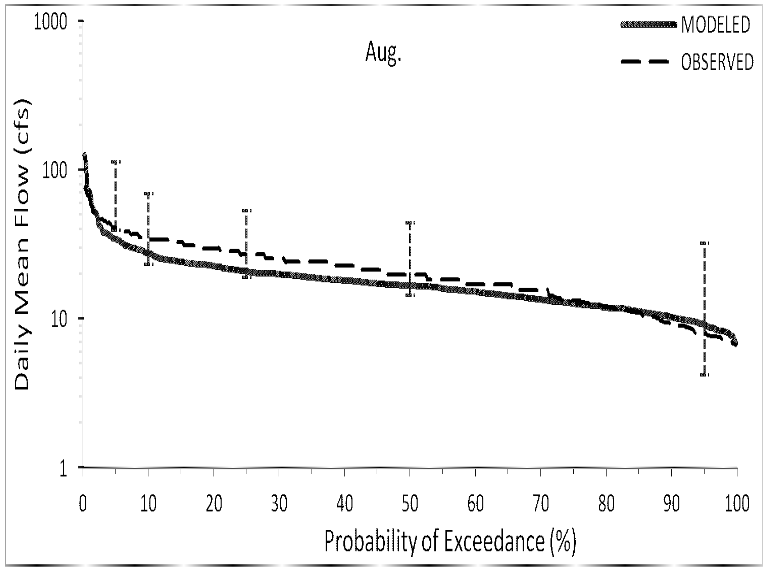
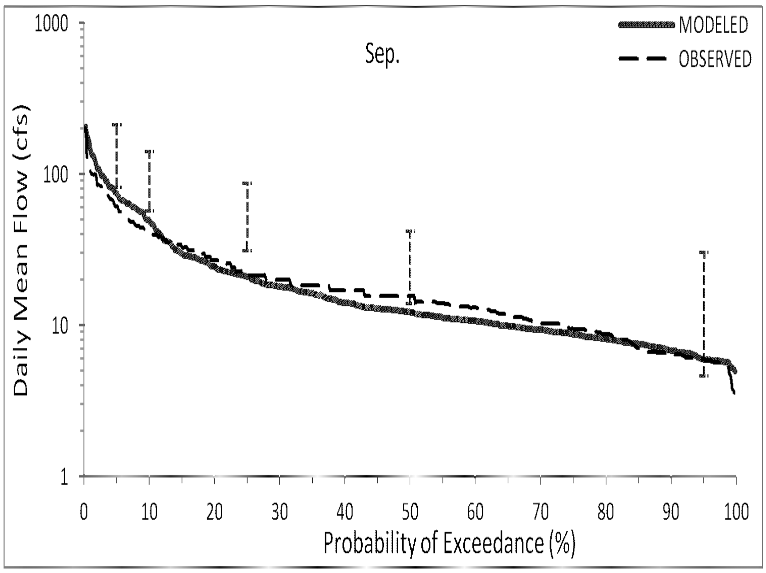
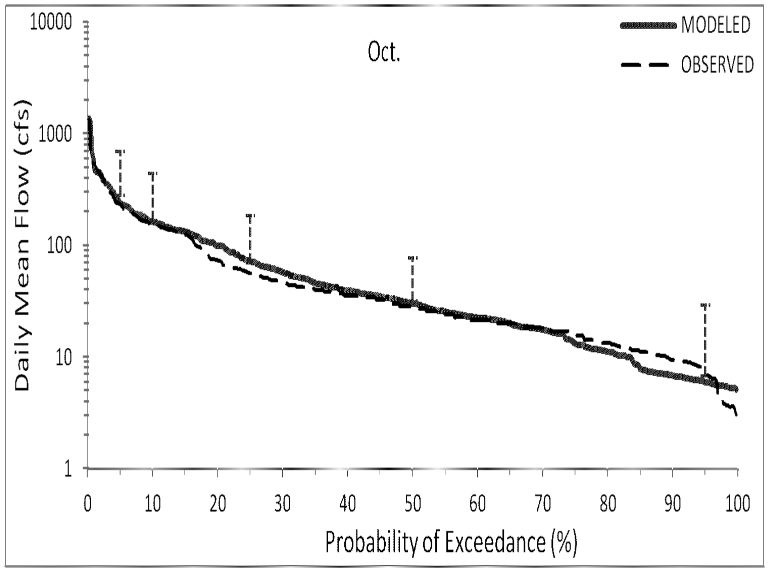

Jan.
Feb.
Mar.
Apr.
May
Jun.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100

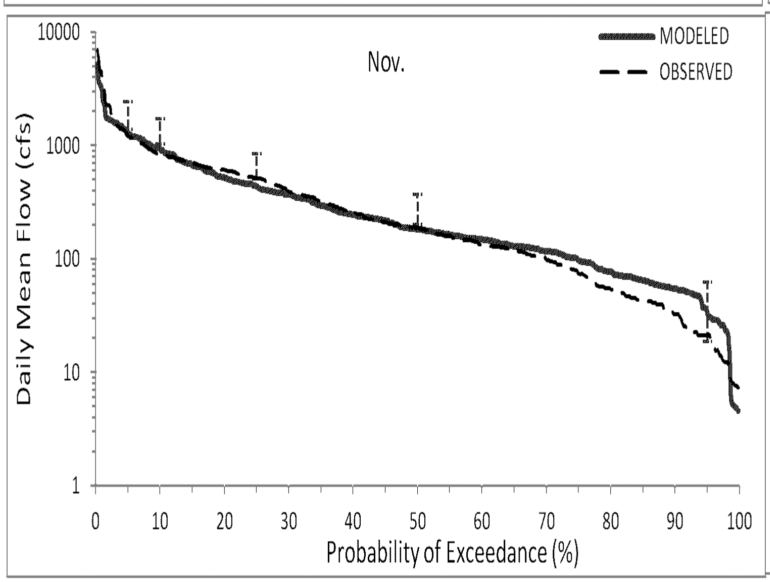
Figure 11. Big Elk Creek monthly (January – June) flow duration curves. Error bars are prediction intervals calculated from USGS StreamStats regional regression equations.


Jul.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
1000
100
10
0 10 20 30 40 50 60 70 80 90 100


Aug.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
1000
100
10
1
0 10 20 30 40 50 60 70 80 90 100


Sep.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
1000
100
10
1
0 10 20 30 40 50 60 70 80 90 100


Oct.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
10000
1000
100
10
1
0 10 20 30 40 50 60 70 80 90 100


Nov.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
10000
1000
100
10
1
0 10 20 30 40 50 60 70 80 90 100

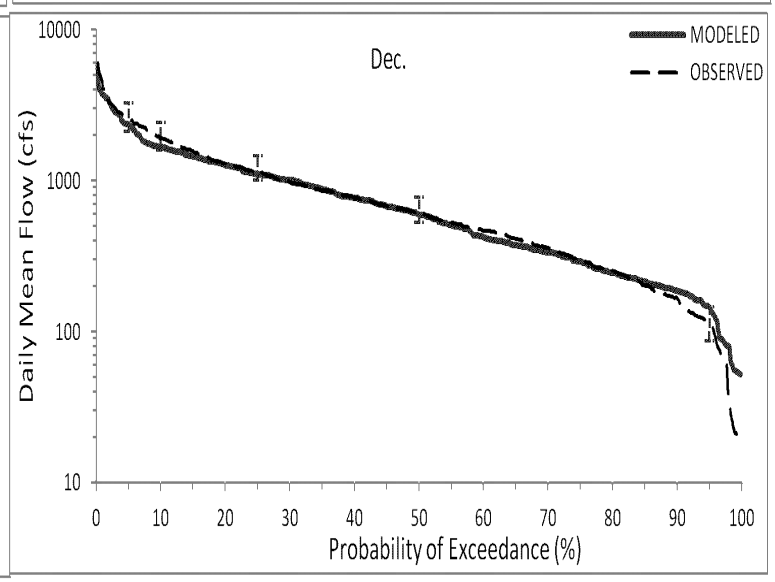

Dec.
MODELED
OBSERVED
Daily Mean Flow (cfs)
Probability of Exceedance (%)
10000
1000
100
10
0 10 20 30 40 50 60 70 80 90 100

Figure 12. Big Elk Creek monthly (July – December) flow duration curves. Error bars are prediction intervals calculated from USGS StreamStats regional regression equations.

Model results indicate that the calibrated model adequately captures the hydrologic behavior of the Big Elk Creek Watershed. Modeled hydrologic characteristics including the overall and seasonal water budget, storm response, and the frequency distribution of streamflow correspond well with estimated Big Elk Creek flow data. A summary of pervious land segment outflow is shown in Table 9. Outflow data suggest that Big Elk Creek streamflow is primarily generated from interflow.

Table 9. Outflow from pervious land segments.

Year	Surface Flow (acre-feet)	Interflow (acre-feet)	Baseflow (acre-feet)	Total Outflow (acre-feet)
1996	8,119	272,827	134,030	414,976
1997	2,117	152,078	119,983	274,178
1998	2,657	201,806	113,081	317,544
1999	4,476	219,758	129,886	354,120
2000	907	101,916	94,776	197,599
2001	770	83,714	75,950	160,434
2002	1,399	114,744	88,968	205,111
2003	1,349	141,158	103,198	245,705
2004	581	52,855	75,516	128,952
2005	2,002	92,803	77,628	172,433
2006	2,726	157,102	102,082	261,910
2007	1,570	119,326	88,349	209,245
2008	898	130,471	103,970	235,339
2009	943	107,364	91,654	199,961
2010	1,150	144,989	100,834	246,973
1996-2010	31,663	2,092,913	1,499,904	3,624,480

Uncertainty Analysis

Analysis of parameter and predictive uncertainty was completed for the Big Elk Creek Watershed HSPF model using a calibration-constrained Monte Carlo approach and PEST software. The method includes 4 general steps:

1. Generate 500 random parameter sets centered on the calibrated parameter set (means equal to calibrated values, variability described by the parameter covariance matrix);
2. Conduct one PEST optimization run for each random parameter set;
3. Retain adjusted parameter sets that provide reasonable predictions;
4. Review parameter and prediction ranges and frequency distributions.

The approach follows uncertainty analysis methods outlined in Doherty (2010) and Donigian & Imhoff (2009). The requirement that parameter sets provide reasonable results was imposed by retaining sets that produced flow duration statistics within USGS StreamStats annual flow duration prediction intervals. An alternative method proposed in Doherty (2010), and applied in Ellis et al.

(2009), is to require that parameter sets provide objective function values below some threshold (e.g., 0.5% of the calibrated objective function value). Here, since the *observed* Big Elk Creek streamflow dataset is in fact estimated using the Drainage-Area Ratio method, the acceptable level of model to measurement error is relaxed for uncertainty analysis.

Following PEST optimization, 110 of 500 random parameter sets provided flow duration predictions within USGS StreamStats prediction intervals. The minimum and maximum parameter values contained in these 110 sets are shown in

Table 10 and parameter boxplots are provided in Figure 14 and Figure 15 (see Figure 13 for a description of data displayed in each boxplot).

Several parameters span the bounds imposed for numerical model stability (e.g., INFILT310, INTFW200, CEPSC300), while others are restricted to a relatively narrow range (e.g., INFILT120, AGWRC000, IRC000). The level of uncertainty associated with individual parameters is likely attributable to two main factors:

1) The streamflow dataset used for model calibration - As previously discussed in this report, calibration data consisted of estimated streamflow at the Big Elk Creek Watershed outlet. A high level of uncertainty will be associated with parameters that have a minor effect on total streamflow at the outlet. This includes parameters for developed land segments (INFIL310, UZSN300, etc.) since the total area of developed lands in the watershed is minimal relative to forest and pasture cover.

2) Model structural error - Parameter uncertainty is further influenced by model structural error, which can be described as inadequacies in the representation of real-world processes by the model. In this case, the *lumped* nature of parameters in space and time gives rise to a wider range of parameter values than would be observed if spatial and seasonal variability were more explicitly accounted for.

Results of uncertainty analysis results show that streamflow predictions are most sensitive to parameters related to interflow and groundwater outflow from pervious land segments (IRC000; AGWRC000; BASETP000; LSZN000). For subsurface storage and flux parameters configured to vary by land cover type, flow predictions are most sensitive to parameters specific to forested land segments (LZETP100; INTFW100). The importance of these parameters is related to the large contributions of interflow and groundwater flow to total outflow from pervious land segments (see Table 9), and the dominance of forest cover in the Big Elk Creek Watershed. The dominance of forested cover is also evident from the high sensitivity of flow predictions to parameters related to surface infiltration and storage in forested land segments (INFILT120; CEPSC100; UZSN100), relative to those specific to pasture and developed segments.

Table 10. Summary of parameter values providing near-calibrated results. The reported bounds are those imposed for numerical model stability.

Parameter Name	Minimum	25th Percentile	Median	75th Percentile	Maximum	Bounds
LZSN000	2.0	2.2	2.4	2.6	3.6	2.0 - 15.0
INFILT110	0.001	0.019	0.049	0.150	0.5	0.001 - 0.5
INFILT120	0.091	0.118	0.130	0.139	0.17	0.001 - 0.5
INFILT210	0.001	0.020	0.169	0.5	0.5	0.001 - 0.5
INFILT220	0.021	0.337	0.443	0.5	0.5	0.001 - 0.5
INFILT310	0.001	0.001	0.001	0.5	0.5	0.001 - 0.5
INFILT320	0.001	0.001	0.232	0.5	0.5	0.001 - 0.5
AGWRC000	0.98	0.98	0.98	0.98	0.98	0.85 - 0.999
DEEPFR000	0.00001	0.00001	0.00001	0.00001	0.15	0.00001 - 0.5
BASETP000	0.01	0.04	0.05	0.06	0.1	0.001 - 0.2
AGWETP000	0.001	0.001	0.001	0.001	0.041	0.001 - 0.2
UZSN100	0.795	1.9	2.0	2.0	2.0	0.05 - 2.0
UZSN200	0.1	0.4	1.6	2.0	2.0	0.05 - 2.0
UZSN300	0.1	0.1	0.1	2.0	2.0	0.05 - 2.0
INTFW100	1.5	8.3	10.0	10.0	10.0	1.0 - 10.0
INTFW200	1.0	1.0	8.1	10.0	10.0	1.0 - 10.0
INTFW300	1.0	1.0	7.9	10.0	10.0	1.0 - 10.0
IRC000	0.4	0.4	0.4	0.4	0.5	0.3 - 0.85
CEPSC100	0.3	0.4	0.4	0.4	0.4	0.1 - 0.4
CEPSC200	0.01	0.01	0.06	0.19	0.2	0.01 - 0.2
CEPSC300	0.01	0.01	0.02	0.2	0.2	0.01 - 0.2
LZETP100	0.4	0.4	0.4	0.5	0.6	0.4 - 0.8
LZETP200	0.1	0.2	0.3	0.4	0.8	0.1 - 0.8
LZETP300	0.1	0.1	0.5	0.8	0.8	0.1 - 0.8

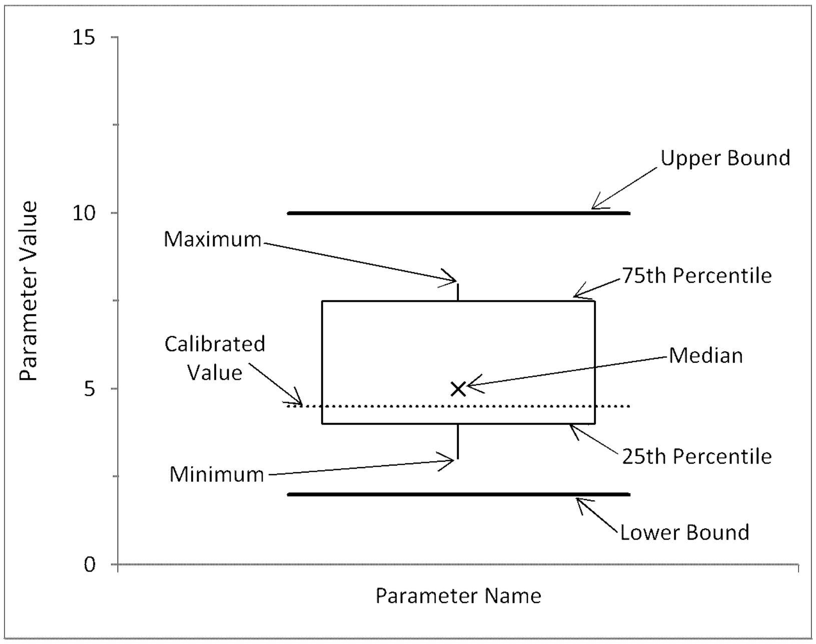


Figure 13. Example parameter boxplot.

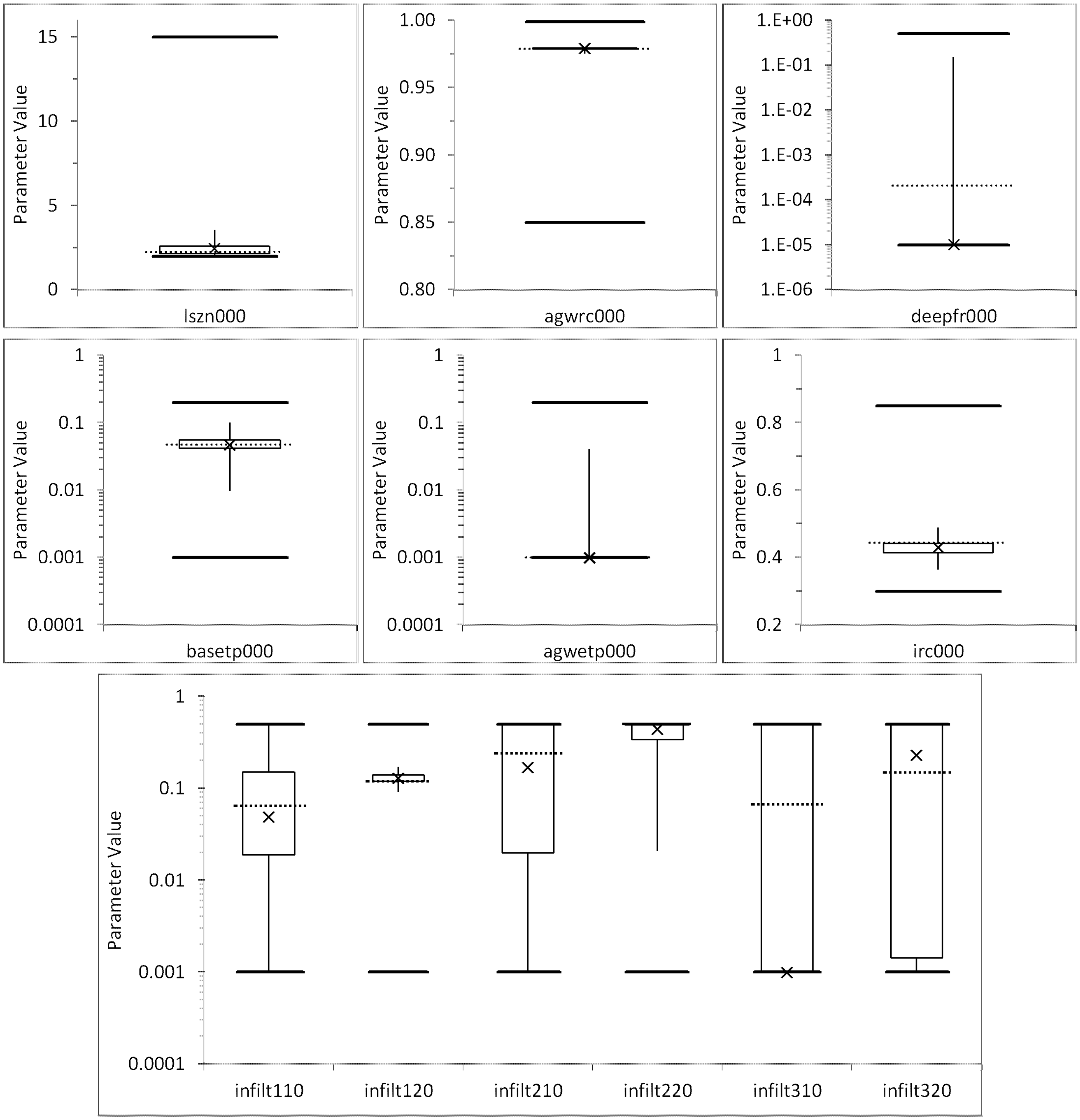


Figure 14. Parameter boxplot showing summary statistics, upper and lower parameter bounds (solid lines), and calibrated values (dotted lines).

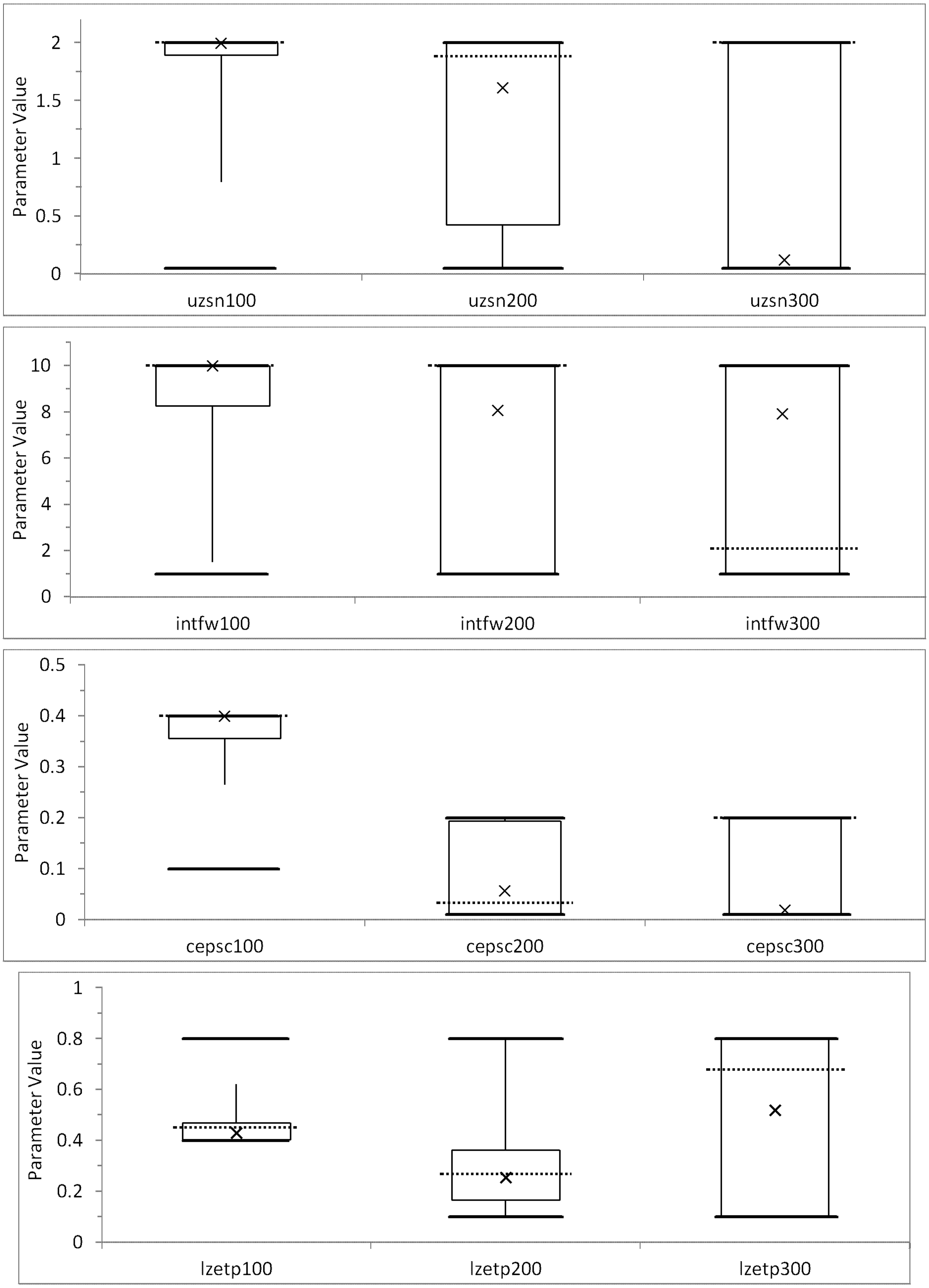


Figure 15. Parameter boxplots showing summary statistics, upper and lower parameter bounds (solid lines), and calibrated values (dotted lines).

Parameter sets provide a wide range of PEST objective function values (3,517 to 4,439; calibrated objective function value = 3,482). Boxplots displaying descriptive statistics for component objective functions (i.e., from each observation group) and the total objective function are provided in Figure 16.

Parameter sets allow for a review of the predictive uncertainty of the Big Elk Creek Watershed HSPF model. Predicted values of Big Elk Creek flow measures used in the calibration objective function (total volume, baseflow volume, summer volume, winter volume, storm volume, and mean storm peak flow) are summarized in Table 11. Minimum and maximum flow duration statistics are illustrated in Figure 17.

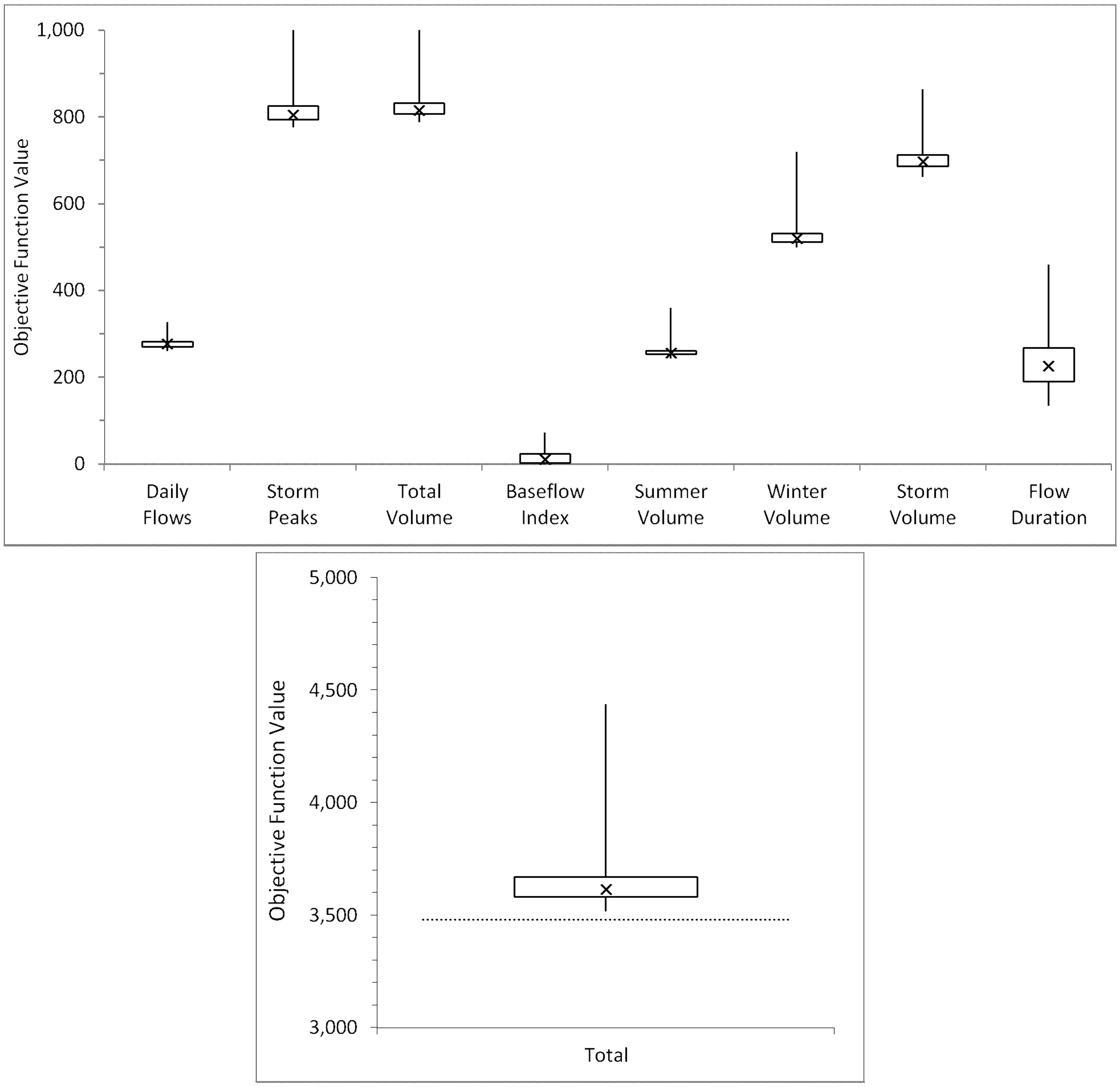


Figure 16. Component (top) and total (bottom) objective function boxplots. Dotted lines are calibrated objective function values.

Table 11. Summary statistics for predicted Big Elk Creek flow volumes/storm peaks. The reported observed values are those obtained from the Drainage-Area Ratio method.

	Total Vol. (100,000 acre-ft)	Summer Vol. (100,000 acre-ft)	Winter Vol. (100,000 acre-ft)	Storm Vol. (100,000 acre-ft)	Mean Storm Peak (cfs)	Baseflow Index
Minimum	36.26	1.44	18.45	2.61	2,009	0.40
25th Percentile	38.03	1.50	19.40	2.75	2,167	0.42
Median	38.24	1.54	19.51	2.78	2,192	0.42
75th Percentile	38.34	1.57	19.60	2.79	2,223	0.43
Maximum	38.92	1.73	19.90	2.89	2,272	0.46
Observed	38.36	1.52	20.45	3.17	2,350	0.44

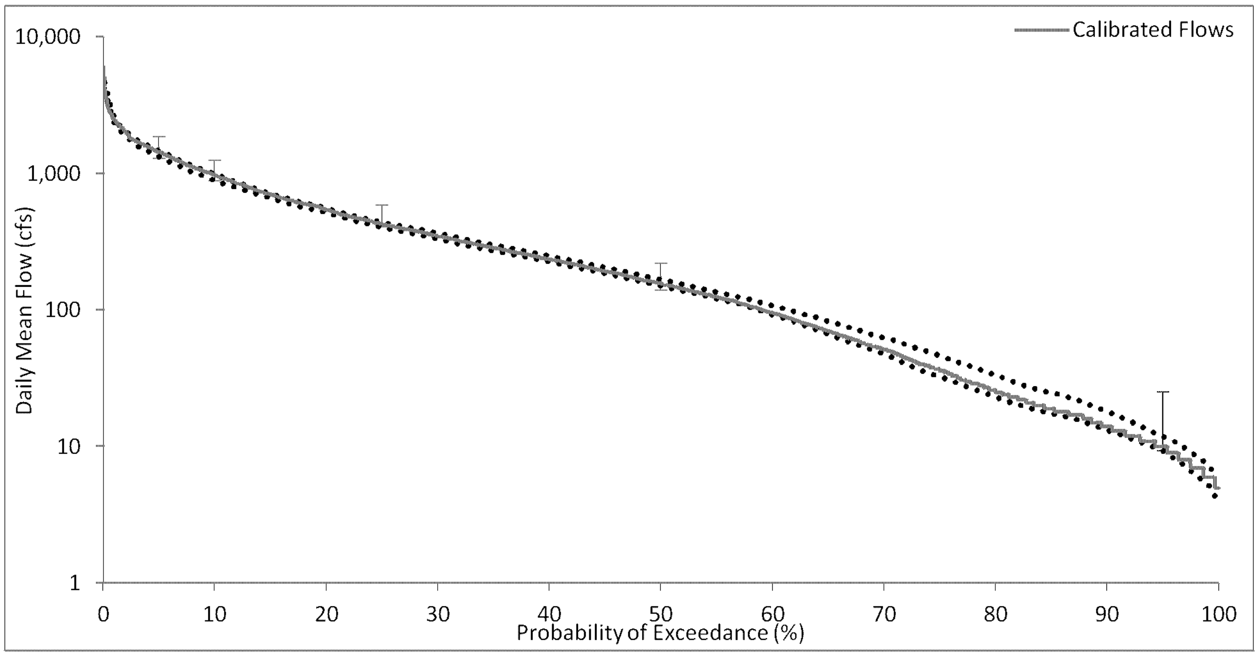


Figure 17. Minimum and maximum flow duration statistics obtained from uncertainty analysis (dotted lines) and the calibrated flow duration curve. Error bars are USGS StreamStats prediction intervals for Big Elk Creek Q5, Q10, Q25, Q50, and Q95 flows.

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Appendix A. Modeled and Observed Big Elk Creek Hydrographs

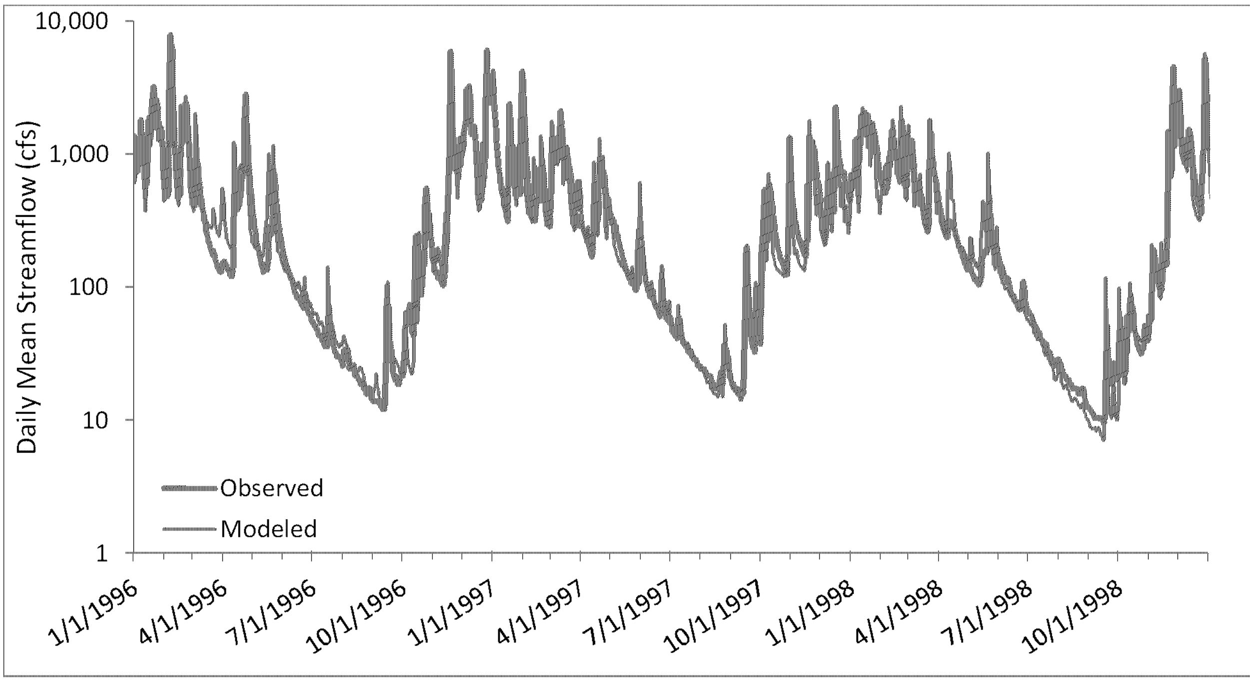

Figure 18. 1996-1998 modeled and observed Big Elk Creek streamflow.

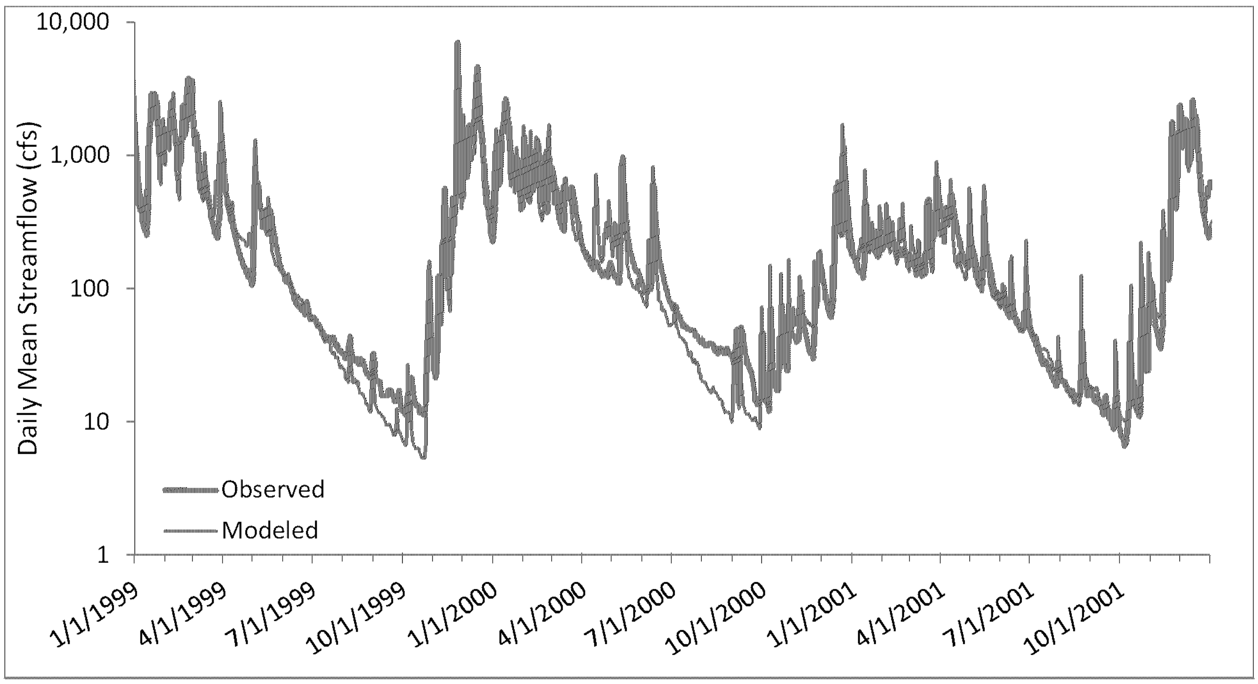

Figure 19. 1999-2001 modeled and observed Big Elk Creek streamflow.

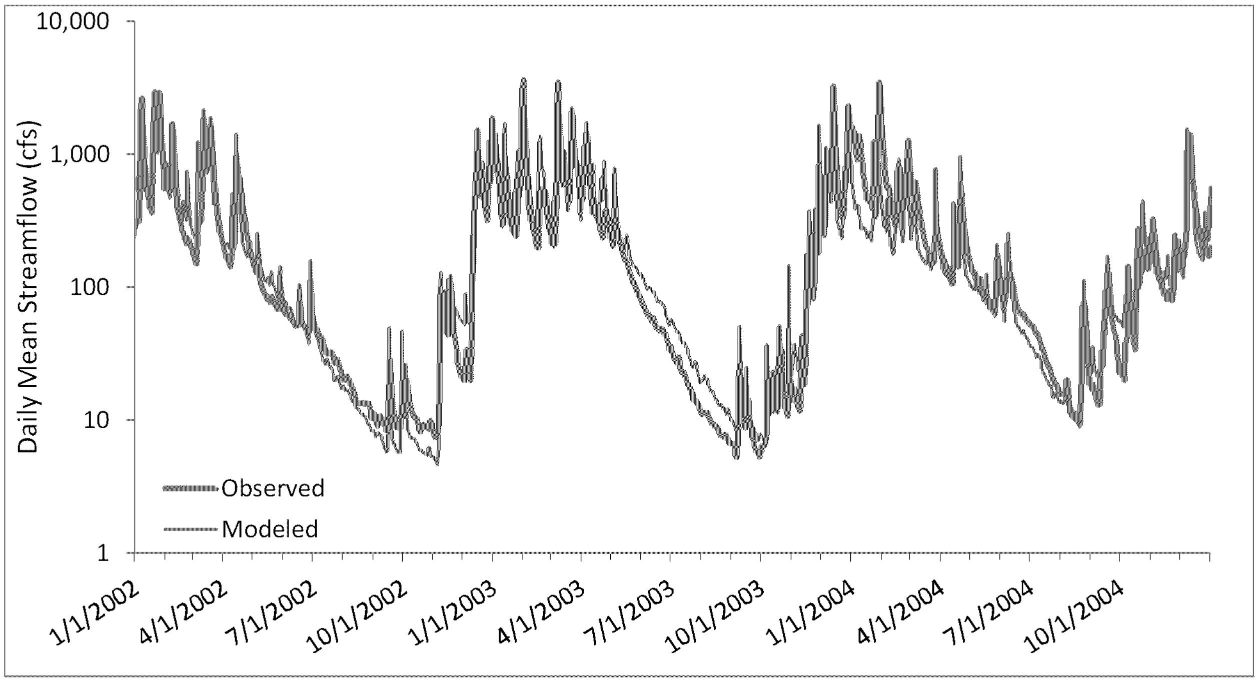

Figure 20. 2002-2004 modeled and observed Big Elk Creek streamflow.

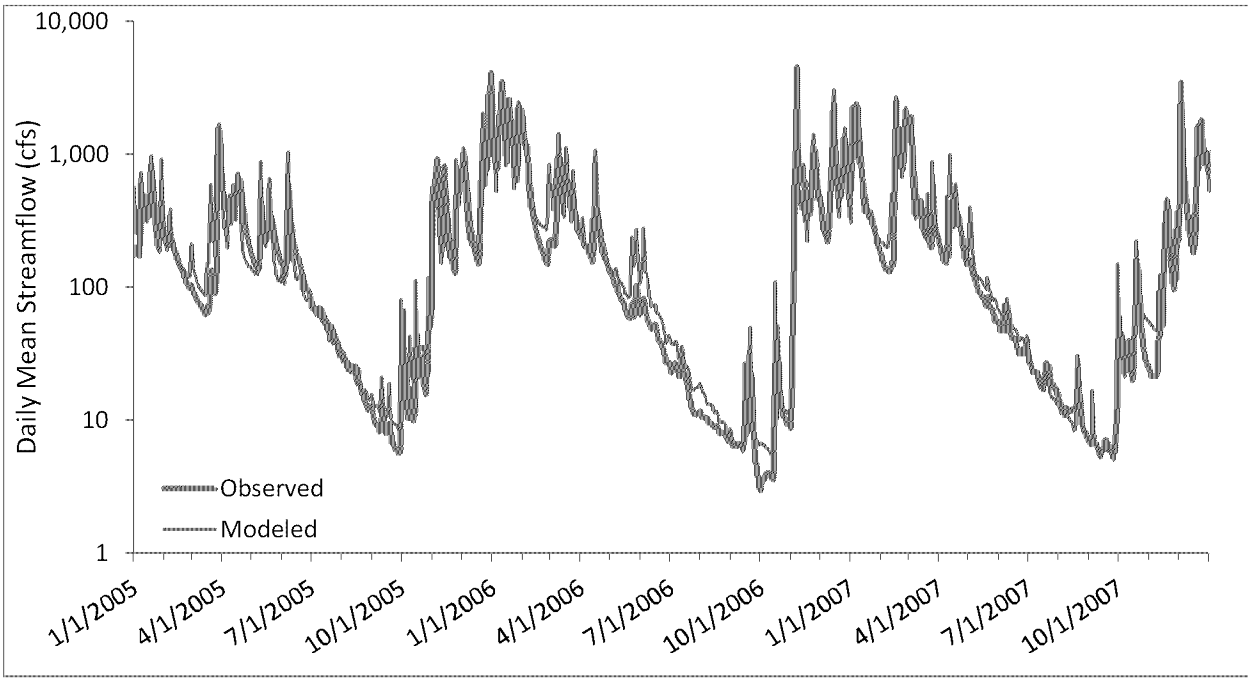

Figure 21. 2005-2007 modeled and observed Big Elk Creek hydrograph.

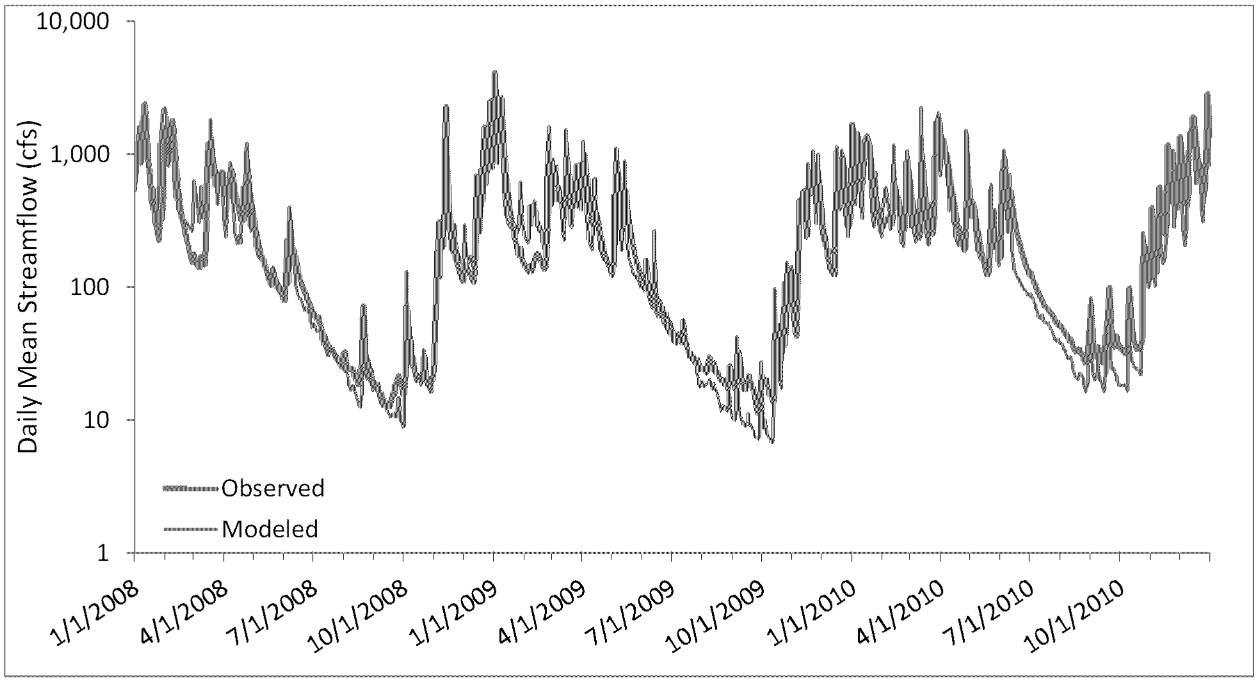

Figure 22. 2008-2010 modeled and observed Big Elk Creek streamflow.

Appendix B. Calibrated Parameter Values

Table 12. Calibrated values of parameters adjusted through PEST calibration.

Parameter Name	Starting Value	Calibrated Value	Bounds
LZSN000 (inches)	8.0	2.3	2.0 - 15.0
INFILT110 (in/hr)	0.05	0.064	0.001 - 0.5
INFILT120 (in/hr)	0.05	0.118	0.001 - 0.5
INFILT210 (in/hr)	0.05	0.238	0.001 - 0.5
INFILT220 (in/hr)	0.05	0.5	0.001 - 0.5
INFILT310 (in/hr)	0.05	0.067	0.001 - 0.5
INFILT320 (in/hr)	0.05	0.1	0.001 - 0.5
AGWRC000 (day^{-1})	0.99	0.98	0.85 - 0.999
DEEPFR000 (-)	0.001	0.0002	0.00001 - 0.5
BASETP000 (-)	0.03	0.05	0.001 - 0.2
AGWETP000 (-)	0.05	0.001	0.001 - 0.2
UZSN100 (inches)	0.5	2.0	0.05 - 2.0
UZSN200 (inches)	0.5	1.9	0.05 - 2.0
UZSN300 (inches)	0.5	2.0	0.05 - 2.0
INTFW100 (-)	1.0	10.0	1.0 - 10.0
INTFW200 (-)	1.0	10.0	1.0 - 10.0
INTFW300 (-)	1.0	2.1	1.0 - 10.0
IRC000 (-)	0.5	0.4	0.3 - 0.85
CEPSC100 (inches)	0.2	0.4	0.1 - 0.4
CEPSC200 (inches)	0.1	0.03	0.01 - 0.2
CEPSC300 (inches)	0.1	0.2	0.01 - 0.2
LZETP100 (-)	0.8	0.5	0.4 - 0.8
LZETP200 (-)	0.6	0.3	0.1 - 0.8
LZETP300 (-)	0.6	0.7	0.1 - 0.8